Functional Assessment of Created, Restored, and Replaced Fish Habitat in the Fraser River Estuary

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Introduction

The Fraser River estuary is probably the most intensively managed estuarine ecosystem on the Pacific coast of Canada because of the importance of the fish populations in the lower river and the intensive human use of the region. For example, the Fraser River supports the largest wild chinook population of any single river system in the world. The particular population, in the Harrison River, is of the life history type which shows an adaptation to estuarine rearing (Levings 1998). Because of the burgeoning human population of Greater Vancouver (population currently about 1.5 million people located primarily within the estuary) and the concentrations of marine industry such as deep-sea ports, it is a challenge to achieve sustainability.

In this paper I provide an overview assessment of bioengineering projects for restoration and compensation at the estuary. For comparison, I have commented on natural processes that lead to development of the various habitats. Over the past decade or so, fish habitat managers have developed techniques to try and achieve "no net loss of productive capacity of fish habitat" as specified under Fisheries and Ocean Canada's policy. Fish habitat mitigation[1], compensation[2], and restoration are the key strategies to achieve this goal. Procedures have included vegetation transplants, channelization, artificial reef construction, and other techniques. Levings and Nishimura (1997) described the Fraser River estuary and summarized a detailed functional assessment of brackish marsh restoration projects in the estuary. In this paper, I provide comments on the other seven primary habitats.

Types of Habitat

For the purposes of this paper, I recognize eight (8) primary fish habitats in the estuary: brackish marshes, eelgrass, sand flats, mud flats, riparian vegetation, side channels, wet meadows, and salt marshes. Because of the differences in fish habitat classification methods (see Thom and Levings 1994) that have been used in the Fraser estuary it is difficult to provide both qualitative and quantitative estimates of fish habitat loss since European settlement. Exclusive of Sturgeon and Roberts Bank and Boundary Bay (total area of about 244 km^2), it is estimated that there were about 1032 km^2 of vegetated habitat (Levings 1998) in the estuary in the late 1890s, but the historical extent of unvegetated areas such as sand and mudflats has not been estimated. Most authorities agree (summarized in Kistritz et al. 1996) that between 70-90% of the wetland habitat has been lost since the late 1800s. Estimates of increase in habitat by bioengineering and natural processes are scarce. Kistritz (1996) calculated a net gain, primarily through restoration, of brackish marsh of about six ha in past decade or so, with an accompanying loss of sand and mudflat habitat that was planted with sedges (primarily *Carex lyngbyei*). This gain was achieved over the past 15 years or so during a period of industrial activity, and likely indicates an improvement in the management of the estuary. Hutchinson et al. (1989) suggested that brackish and freshwater marsh in the estuary and lower river had expanded substantially in the past century. There has been no systematic investigation of these expansions, but they likely occurred at a few locations several decades ago, possibly in response to training wall construction as explained below.

Procedures for Habitat Restoration: Successes and Problems

Over decades or centuries, natural succession of vascular plant communities in estuaries and large rivers occurs as shallow water fills in with sediment, allowing the development of marshes, then wet meadows, riparian vegetation and finally wetland forests (Teversham and Slaymaker 1976). I have arranged my description of the various habitats to conform with this scheme.

Sand and Mudflats

Bioengineering

Because of the relatively low ecological value traditionally assigned to shallow water, unvegetated habitat in the estuary (e.g., Williams and Colquhoun 1987) there has been no attempt at creating sand and mudflats in the region. Many hectares of unvegetated habitat has likely been created by disposal of dredged sand (Envirocon 1980) but this has not been documented. In general, compensation for loss of shallow-water, unvegetated habitat has been difficult because of unavailability of terrestrial or filled habitat which could be lowered to proper elevation for fish use.

Because of the difficulty in creating shallow water sand and mudflat habitat in the estuary, there have been some "like for unlike" habitat switches in some parts of the estuary. Artificial reefs were first developed in 1983, at the Roberts Bank coal-loading terminal, by placing concrete pipe and pilings on the sea floor. The artificial reef was created to provide compensatory habitat for losses of habitat, including shallow-water sand and mud-flat habitat, that occurred through construction. The results were recently examined as part of a functional assessment of several bioengineering projects on Roberts Bank. An ecological survey conducted in 1997 (Subsea 1997) found that the hard substrates had been colonized by red algae, tunicates, hydroids, and wide variety of other epifauna and epiflora. However, the pipes and pilings appeared to be sinking into the substrate, and the -term future of the structures may be uncertain. The reefs also attract predatory fishes such as rockfish, which may feed on juvenile salmonids.

Natural Processes

Sand and mud-flat habitats are developed by bedload and washload sediments arriving into the estuary from upstream erosion. Wave and current energy and other hydraulic processes will tend to move sediments to an equilibrium slope. For example, on the foreshore of Sturgeon Bank, exposed to the Strait of Georgia, sand and mud flats show approximately a 1:20 gradient. As mentioned above, these habitats are usually rated as low value estuarine habitat based on their lack of vascular plant communities, but their function has never been adequately assessed. We do know that chinook salmon juveniles use sand flats on Sturgeon Bank and concentrate in the low-tide refuges for rearing (Levings 1980). It is likely that sand and mud flats are important building blocks for brackish marsh and other key habitats, and therefore any impairment in their development (e.g., blockage or removal of sediment from upstream sources) should be avoided.

Brackish Marsh

Bioengineering

Studies conducted under the DFO Fraser River Action Plan (1990–1993) have investigated the relative successes of brackish marsh transplants (especially sedge, *C. lyngbyei*) in the Fraser River estuary. They have shown that if elevations and sediment conditions are satisfactory, the plants will survive, and they are quite quickly colonized by invertebrates used as fish food (Levings and Nishimura 1996). However in a number of instances the transplanted marshes were found to be higher in the intertidal zone than natural marshes, and thus were relatively less accessible to fish. More recently, we conducted a study at the estuary in September 1996 at 13 transplanted and six natural sedge marshes to investigate the below-ground rhizome biomass as an index of restoration success. Results showed that the mean below ground biomass (excluding the top five cm of fresh material and previous years' leaves and stems) for transplanted marshes was not statistically significant ($p>0.05$). These results suggest that the transplanted marshes, which ranged in age from five to eight years, had developed rhizome biomass similar to natural marshes.

The above studies only examined a small subset of the marsh restoration projects, and there are numerous transplant projects that have not been assessed because no formal follow-up procedures were required. As well, except for very basic botanical measurements (e.g., plant survival), ecological performance criteria are not used.

Another class of restoration projects for brackish marsh, which has conducted by numerous citizens' groups, has involved removal of log debris from marshes. Anecdotal evidence suggests that the plants increase their productivity when debris is removed. However, there has been no published follow-up work to document these benefits.

Brackish marsh restoration or creation has been a common practice in the estuary, resulting in habitat switches in several locations, as documented by Kistritz (1994) and Adams and Williams (1998). In most instances sand or mud flat habitat has been raised or otherwise modified to allow sedges to be transplanted at the proper elevations.

Natural Processes

Because the Fraser River carries a very large bedload of sand as well as washload of mud, shoal areas are built up quickly which can then lead to colonization by brackish marsh. Thus an unquantified area of marsh has developed by natural processes (Hutchinson et al. 1989). Breakwaters and causeways have stopped this type of accretion in several areas of the delta, particularly near Iona Island where wave energy is focused. (Pomeroy et al. 1981). In other areas (e.g., Duck-Barber-Woodward Island in the inner estuary), construction of training walls has created backwater areas where sedimentation has led to development of marsh islands. On the foreshore of Lulu Island it appears the sediment from the washload is sufficient to allow seaward expansion of the foreshore marshes (e.g., seaward side of Lulu Island) (Hutchinson et al. 1989).

Sand islands were created in past decades from clean sand dredged for channel maintenance in numerous locations in the estuary. These locations have been successfully colonized by sedge marshes (e.g., Wiley, 1984), although this phenomenon has not been systematically assessed.

Eelgrass

Bioengineering

There has been one eelgrass (*Zostera marina*) transplant conducted in the Fraser River estuary. In November 1991, 96000 sprigs were transplanted into an area near the Tsawwassen Ferry Terminal, as part of a project to compensate for habitat lost owing to construction of a parking lot. Kistritz and Gollner (1995) conducted an evaluation of part of the transplant site in March 1995. Shoot density at the transplant site was 127 shoots/m^2 (s.e. 8.6) compared to 75 shoots/m^2 (s.e. 3.6) for a nearby reference site. Because of problems in identifying the boundaries of the original transplant areas, it was difficult to determine if the shoot density found was representative of survival for the 1991 plantings.

Natural Processes

Several detailed studies have examined the spread of native eelgrass (*Zostera marina*) on Roberts Bank, particularly in the intercauseway area. Harrison (1987) concluded that expansion of these eelgrass beds was enhanced by the deflection of turbid water from the Fraser River by the coal port causeway. Spread of the eelgrass was by encroachment of the rhizomes to sandflat habitat. An introduced eelgrass (*Z. japonica*) has also spread onto Roberts and Sturgeon Bank, likely by seeds. Expansion of this species onto Sturgeon Bank may have been enhanced by recent improvements in water quality because of diversion of sewage from the intertidal zone (Nishimura et al. 1996).

Salt Marsh

Bioengineering

An unsuccessful attempt was made to transplant cores of pickleweed (*Salicornia virginica*) into the Iona Island foreshore. Failure was likely due to sediment instability and salinity conditions (Pomeroy et al. 1981). However a related species has been cultivated elsewhere (Kamps 1962) and it is possible that salt marsh could be restored at the Fraser River estuary under the correct conditions.

Debris removal programs in salt marsh habitat have occurred, especially in Boundary Bay. However, there has not been any documentation of the benefits.

Natural Processes

Salt marsh plants are not adapted to the brackish conditions near the river mouth where sand and mud are deposited. Salt marshes are dependent on marine processes such as longshore drift for sediment supply and expansion. For example, before construction of the BC Ferry Terminal causeway, the Tsawwassen salt marsh was relying on eastward movement of sand from Point Roberts Bluff. Saltmarsh vegetation (*Salicornia virginica*, *Distichlis spicata*) successfully colonized a dredge-spoil island on Sturgeon Bank, near Steveston, resulting in the development of 0.5 ha of habitat within about 10 years (Levings 1998).

Wet Meadows

Bioengineering

There has been no attempt, as far as is known, to restore this kind of habitat. However because certain brackish marsh restoration projects have been built too high in the intertidal zone, they are dominated by wet meadow species (e.g., rushes such as *Juncus effusus* (Levings and Nishimura 1996). This habitat was once one of the most extensive vegetation units in the Fraser River estuary (Kistritz et al. 1996). However because the habitat occupies the highest elevation of the intertidal zone, and in some instances, is actually on the flood plain, wet meadows were the first areas to be diked and converted to farmland. The importance of wet meadows as fish habitat is poorly documented, but these vegetation communities, as well as wetland forests, supplied significant amounts of carbon to the estuary ecosystem before they were converted to agricultural areas (Healey and Richardson 1996).

Natural Processes

Wet meadows develop on accreted sediment at higher elevations in areas that are infrequently flooded. In the botanical succession process, they follow brackish marshes but precede riparian vegetation. Eventually these habitats likely become floodplain forests, which are important for maintaining the integrity of the delta by reducing erosion.

Riparian Vegetation

Bioengineering

Riparian vegetation is planted on relatively steep shorelines where the plants can stabilize sediment as well as provide detritus and insect production. There have several kilometers of shoreline in the Fraser River estuary that have been transplanted with riparian vegetation such as willows (*Salix* spp.) and red ochre dogwood (*Cornus stolonifera*) (DFO, unpublished). The plants characterizing this particular habitat are said to show high survival after transplanting (Adams and Whyte 1990) but there are no published assessments available in the Fraser River estuary.

Natural Processes

Because riparian plants do not tolerate regular flooding, they do not necessarily colonize the intertidal zone. Riparian vegetation establishes on the river shorelines that have been built up by the process of sedimentation, especially following major freshets when the elevation of sand bars and banks are raised. Riparian vegetation has also colonized several dredged sand islands in the Fraser River estuary (Envirocon 1980).

Side Channels

Bioengineering

In efforts to recover shallow water habitat, there have been a number of projects in the Fraser estuary where ditches or channels were cut into terrestrial or irregularly flooded land. For example, at Iona Island, about 400 m of ditch was dug into a grassy field, enabling high-tide flood waters to penetrate the field. Preliminary analyses showed that aquatic invertebrates colonized the constructed channel (Levings and Nishimura 1996). In another project, a channel about two km long was dug through a cottonwood stand, then connected to a culvert bringing water into the site from the North Arm of the Fraser River at Burnaby Bend. In this instance, riparian vegetation and brackish marsh was planted along the channel edge to help stabilize the sides of the channel (DFO, unpublished data).

Natural Processes

The processes leading to natural development of side channels in the Fraser estuary is dependent on the particular habitat being considered. For example side channels through sand flats are usually created by erosion due to river currents, whereas those through mud flats develop as water drains off following high tides (e.g., Luternauer 1980). Channels through salt marshes develop by tidal drainage as well, but in this instance the banks of the channels are stabilized by plants, as observed at the Tsawwassen salt marsh on Roberts Bank (Hillaby and Barrett 1976).

Summary : What Ecological Processes Does This Habitat-By-Habitat Approach Ignore?

After about a decade of restoration activities in the Fraser River estuary, applied ecologists have accumulated valuable experience with applying bioengineering techniques to restore or replace lost habitat. However, few data sets exist for for assessing the “value” of particular projects. This brief assessment suggests all the bioengineering restoration and compensation techniques reviewed have had varying degrees of success—or at least enough success that their proponents continue to seek, and obtain, funding for their work. Unfortunately, even though habitat conversion, creation and replacement is widespread in the Fraser River estuary, little consideration has been given to the landscape level consequences of the many individual restoration projects that have been undertaken. Therefore, before future bioengineering projects are implemented, there are several important ecological and policy considerations that need to be taken into account to place restoration efforts in the context of estuary management plans. Some of these recommendations are summarized below.

1. Implement Landscape -Level Planning

Bioengineering projects to date have been considered on a project by project basis without explicit consideration of landscape level objectives. As the examples have illustrated, bioengineering projects are not necessarily reflective of the spatial patterns of the eight primary habitats at the landscape level. The science of landscape ecology should be applied to estuarine habitats when planning restoration in specific reaches of the estuary. As explained, the sediments, plants, and water levels interact both in time and space to create the landscape units, or mosaics of habitats, that we see at any point in time. The Oceans Act (1997) emphasizes ecosystem management, and the rapidly developing science of ecological geography (e.g., Bailey 1996) shows that habitats cannot be managed in isolation from each other. Therefore, we recommend that existing GIS inventories (such as those maintained by the Fraser River Estuary Management Program) be upgraded and used to compare the proportional representation of the various habitat types at various spatial scales in the Fraser River estuary currently to historical patterns. This will facilitate an objective appraisal of which habitat types have been lost or gained and in what areas. At a minimum, this information can be used in the future to give higher priority to those bioengineering projects expected to restore or recreate those habitat types that have sustained the greatest loss in the past rather than on an ad hoc project-by-project basis.

2. Ecosystem Research and Monitoring

After about two decades of applied fish habitat research in the Fraser River estuary and others in the northeast Pacific, there are still major uncertainties about the fish habitat value of specific habitat types. In addition, it is unclear what the benefits are of bioengineering one habitat type over another. For example what is the role of sand and mud flats in the estuarine ecosystem compared to brackish marsh habitat? Should we continue to tradeoff sand and mud flat habitats for brackish marsh? Although this situation cannot be rectified immediately, standard criteria should be developed for assessing habitat differences in the future. To be effective, these criteria need to be monitored regularly at restored and natural areas to determine whether restored areas are producing the expected results.

3. Ecological Succession

Natural processes such as sedimentation and colonization by various plant species convert one habitat type to another over time, but current habitat restoration does not take this phenomenon into account. The ecological succession of plant communities occurs on a scale of decades, and is usually punctuated by rapid erosion and accretion events such as those that occur during major freshets. Responsible plans for ecosystem and habitat management must take these changes into consideration, and a long-term perspective is required.

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[1] In Canadian terminology, refers to alternative siting and procedures to reduce impact

[2] Refers to what is usually called mitigation in US policy language